Protocol for Monitoring of Moisture in the Walls of a Home

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ABSTRACT

The moisture performance of exterior wall systems is a subject of interest to the building community, and there is a need for more empirical data and validated analytic procedures. A project underway demonstrates a hardware setup and operational methodology for gathering data that may be used in the field evaluation of building wall performance, and that contributes to the development of modeling procedures.

Introduction

Background

While the effects of moisture on the performance of building envelopes have long been recognized, the interest of the building community in moisture performance has been focussed in recent years by reports documenting severe damage associated with condensation in homes in a cold climate (Merrill and TenWolde 1989), and with rainwater leakage in recently-built homes finished with exterior insulation and finish systems (EIFS) (Johnston 1995). However, improved methods for analyzing and evaluating the moisture performance of buildings are needed.

Both empirical and analytic methods may be useful in evaluating building envelope performance. Analytic methods can contribute to the selection of building envelope designs based on expected performance in the field, as well as assisting in the diagnosis of failures. Empirical performance evaluation of building envelope systems provides direct evidence that can help to overcome the resistance of home builders and building codes in embracing new building technologies. Both methods can contribute to the evaluation and use of designs incorporating increased energy efficiency.

Objectives

This project addresses the need for a measurement methodology to support both empirical and analytic approaches. The specific objectives of the project are:

1) Development of hardware and a methodology for use in monitoring moisture content in wood materials at a number of locations in building envelopes under service conditions.

2) Generation of detailed data to be used in the development and calibration of a mathematical model of wood-frame wall system thermal and moisture dynamics.

Air flow through wall sections can dominate diffusion as a transport mechanism; however, continuous measurement of air flow is not being performed in this project. Instead, detailed data for use in modeling will come from wall sections in which air leakage has been minimized, and in which diffusion and adsorption/desorption are the primary mechanisms.

The project is anticipated to continue gathering moisture content and related data from a single test home for about one year.

Previous Work

Moisture in wood materials can be measured using the electrical resistance of the wood as an indicator of moisture content. This technique is commonly implemented using hand-held meters, and has been used in both diagnostic work and in research. Several hundred homes in the Pacific Northwest have been evaluated for evidence of moisture accumulation in walls by removing exterior finishes and making one-time measurements with hand-held resistance-type moisture meters (Tsongas 1980; Tsongas 1990).

Little work has been reported in which the moisture content of wood materials has been monitored over an extended period in buildings under service conditions. In one recent project, electric resistance readings were used in measuring wood framing moisture content of assemblies in a large environmental chamber over a 6 month period (Derome and Fazio, 2000).

Methodology

Test Home

Data is being gathered at a test home in Madison, WI. The home is being leased by the project, and will remain unoccupied through the test period, allowing complete control over indoor environmental conditions and reducing the confounding effects of occupancy.

The home is a wood frame house of generally conventional construction. The main floor is approximately 1400 ft^2 (130 m^2) in size, with a full basement, currently unfinished. The basement is a walk-out design, with the exterior grade varying from floor level to about 7 ft (2.13 m) above floor level. Abbreviated typical construction specifications are as follows:

- Poured concrete below-grade foundation walls with 2 in extruded polystyrene insulation, wood framed walls with R-19 fiberglass insulation in above-grade areas of basement, and uninsulated concrete basement floor slab.
- 2 x 6 x 16" oc main wall framing.

- Standard density "R-19" unfaced fiberglass batt wall insulation (R-19 at an installed thickness of 6.25 in).
- 1 inch extruded polystyrene (XPS) wall sheathing. (Several sheathing configurations are used; see Table 1 for specifics in designated test bays).
- Spun polyolefin air barrier over exterior wall sheathing.
- 6 mil polyethylene vapor barrier installed without sealing of edges and joints. (Several vapor barrier configurations are used; see Table 1 for specifics in designated test bays).
- Manufactured wood roof trusses, OSB roof sheathing, and asphalt roofing shingles. Six mil polyethylene vapor barrier installed between drywall and lower chord of trusses.
- Condensing efficiency forced air gas furnace.
- Central air conditioner.
- Central humidifier mounted in furnace plenum.
- Enthalpy type ventilation heat exchanger, with incoming air ducted to central return air duct.

Moisture Probe Design

The moisture probes are the electrodes used in making electrical resistance measurements of the wood. Each moisture probe as used in this study consists of a pair of pins cut from 0.094 in (2.4 mm) diameter stainless steel rod. The probes were installed in four configurations:

- In wood framing, configured to make sub-surface measurements at 0.25 to 0.50 in (6.4 to 12.7 mm) depth.
- In wood framing, configured to make sub-surface measurements at 1.0 to 1.25 in (25.4 to 31.8 mm) depth.
- In wood framing, configured to make surface measurements: Surface to 0.25 in (6.4 mm) depth.
- In OSB sheathing, configured to make surface measurements: Surface to 0.25 in (6.4 mm) depth.

The pins used in sub-surface measurements were left bare for 0.25 in (6.4 mm) at the measurement tip and for a wiring connection at the exposed end, with the remainder of the shaft insulated with FEP heat-shrink tubing for electrical isolation from the wood. The pins used in surface measurements were left bare. The pins were placed in holes sized to provide a press fit at the depth of the desired measurement. All pin pairs were installed 1.0 in (25.4 mm) center to center. The pair of pins forming each probe were installed in a plane parallel with the drywall and sheathing surfaces, as these planes are expected to be isothermal.

The electrical resistance measurement is made by applying a DC excitation voltage across each probe and measuring the resultant current. The resistance of wood varies from about 500 k ohms to 50 G ohms as moisture content ranges from about 25 to 7 percent (James 1988). This yields signals as small as about 0.1 nA, using a 5 VDC excitation in dry wood, which is susceptible to a variety of errors. The cable used for connecting the pins to the data acquisition system was selected for high resistance between conductors and for low dielectric absorption (the transient absorption of energy in the insulation between conductors when a voltage is applied between them) in order to reduce signal errors caused by leakage currents. Since dielectric absorption is not reported as a characteristic by cable manufacturers, we relied on informal bench testing to select a lead cable with acceptable performance. The cable selected has 22 gauge conductors, polypropylene conductor insulation, foil shielding of each of the 2 or 3 wire pairs in the cable, and outer PVC insulation.

Lead wires were connected to the moisture probe pins using nylon-insulated crimp connectors, forming a friction fit with the pins. An effort was made to terminate the shielding for each wire pair about 4 in (100 mm) from the pins, to reduce potential leakage from the wood directly to the shielding. Long runs of unshielded wire were also avoided.

Thermocouples were installed near many of the moisture probes. Type T thermocouple wire, foil shielded and Teflon insulated, was used. The thermocouples were mounted on the surface about 1 inch from the corresponding moisture probe, using masking tape. A length of several inches of lead wire was also taped directly to the surface in a plane expected to be isothermal, to minimize thermal conduction along the wire.

All moisture probes and thermocouples were checked for open circuit or short circuit conditions after installation.

Setup of Test Bays

Twelve stud bays in the home were selected for collection of detailed data to be used in modeling work. These bays include several variations on the basic wall section. To minimize uncontrolled air flow and its confounding effects on model validation, many of the designated test bays were sealed to be as air tight as possible. This was done using caulking at the perimeter joint between framing and sheathing, at framing joints, and at the interface between vapor barrier (or drywall) and framing. To minimize effects of different conditions in adjacent bays, the wall cavities on either side of the test cavities have the same sheathing and vapor barrier configuration where possible. Table 1 summarizes the construction of the test bays.

In each test bay, moisture probes were placed in the top plate, bottom plate, and mid-height in one stud. At each of these locations, one probe was placed approximately 0.5 in (12.7 mm) from the plane of the exterior sheathing, and another 0.5 in (12.7 mm) from the plane of the drywall. (There was one exception, in bay #11, where an additional probe was installed near the plane of the drywall.) In some bays, additional probes were placed in the OSB sheathing near the top, mid-height, and bottom of the wall.

Thermocouples were placed adjacent to all moisture probes in the test bays, as well as on the outside surface of the drywall near some moisture probes.

A total of 82 moisture probes and 103 thermocouples were installed in the 12 designated test bays. The test bay monitoring configuration is also summarized in Table 1.

Table 1. Test Bay Construction and Probe Configuration

Test Bay Designation, (Orientation)	**Sheathing Type**	**Vapor Barrier**	**Intentionally Airtight?**	**Sheathing Joint?** *Note 1*	**Elect Box? (Ht - in)**	**Moisture Probe Locations, (Total Number)** *Note 2*	**Thermocouple Locations, (Total Number)** *Note 3*
1 (W)	½" OSB	No	Tight		-	F (6)	F (6)
2 (W)	½" XPS	Poly	Tight		-	F (6)	F (6)
3 (W)	½" OSB	Poly	Tight		-	F, S (9)	F, S, D (12)
4 (W)	½" XPS	No	Tight	Y	-	F (6)	F, S, D (12)
5 (W)	½" XPS	No	Tight		-	F (6)	F (6)
6 (W)	½" OSB	No	Tight		-	F, S (9)	F,S,D (12)
7 (N)	1" XPS	No	Normal *Note 4*		Y (16")	F (6)	F (6)
8 (N)	1" XPS	No	Tight		-	F (6)	F,S,D (12)
9 (N)	1" XPS	No	Normal	Y	-	F (6)	F (6)
10 (N)	1" XPS	Poly	Tight		-	F (6)	F (6)
11 (N)	1" XPS	Poly	Normal *Note 5*	Y	Y (42")	F (7) *Note 6*	F (7) *Note 6*
12 (N)	½" OSB ½" XPS	No	Tight		-	F, S (9)	F,S,D (12)

Table Notes:

Note 1 Y indicates a sheathing joint over one of the studs forming this bay.

Note 2 Moisture probe locations:
F - 6 probes in framing (top, middle, and bottom)
S - 3 probes in sheathing (top, middle, and bottom)

Note 3 Thermocouple Locations:
F - 6 thermocouples on framing, adjacent to moisture probes.
S - 3 thermocouples on sheathing, adjacent to moisture probes
D - 3 probes on back side of drywall, near moisture probes

Note 4 Bay 7 was made intentionally leaky by putting spacers between the sheathing and framing at one location each at the top and bottom of the wall.

Note 5 The exterior surface of Bay 11 was not sealed airtight. The drywall will be sealed tight to permit leakage only at the electric box.

Note 6 The bottom plate in bay 11 had a split, parallel with the plane of the drywall, about ½ to ¾ from the drywall surface and near the middle of the bay width. Two bottom plate moisture probes were installed, one ½" from the plane of the drywall, one near the right side of the bay, one near the left side. One thermocouple was installed near the right hand probe, and one near the center of the bay width. Other sensors in this bay were installed normally.

To control insulation quality, project members installed the fiberglass batt insulation in each of the 12 designated test bays. Care was taken to place insulation between the moisture probes and the exterior sheathing surface, between the probes and the plane of the drywall, and to bring the insulation into good contact with the framing members along the perimeter of each bay.

Other Moisture Probes

In field investigations of homes with EIFS finishes, and in numerous unpublished anecdotal reports, rainwater leakage sites have been identified at the perimeter of windows and doors, through frame joints in windows, at siding butt joints, and at penetrations in the siding such as those created for light fixtures, utility lines, and deck supports (Johnston 1995). Condensation in wall cavities in cold climates is most likely to occur on solid surfaces that are thermally close to the outside surface of the wall system.

In addition to the test bay probes described above, 64 moisture probes were installed in locations considered susceptible to rainwater leakage or condensation. These probes were installed in framing below windows, below an exterior light fixture penetration, in subflooring below deck attachment points, in several locations in the band joist, and in the framing and OSB sheathing in a bay with no extruded foam insulation (considered to have high condensation potential). These probes are expected to yield general information on the appearance and duration of high moisture levels, rather than exact moisture content values. As such, coincident temperature information is not required, and no thermocouples were installed with the probes. Though not required as part of the current project, 12 probes were installed in the roof framing and sheathing. Table 2 summarizes the placement of these moisture probes.

Table 2. Locations of Additional Moisture Probes

Building Element	Number of Moisture Probes
Framing Near Windows	40
Below Exterior Light Fixture	2
Subfloor	7
Band Joist	7
Stud Bay with High Condensation Potential	4
Other Wall Locations	4
Roof System	12

Several samples of the construction lumber used in framing the test home were oven-dried and weighed. These samples are equipped with moisture probes, placed in the home, and connected to the data acquisition system. Periodic weighing of the samples will provide gravimetric moisture content values, allowing calibration and validation of the resistance data gathered in the study.

Data Acquisition

Lead cables from moisture probes are connected to a multiplexer that allows conditioning of each signal by a single amplifier, eliminating errors associated with amplifier variability. The multiplexer is comprised of electromechanical relays selected and mounted to minimize leakage current, and an associated control circuit. Thermocouple and other signals are also connected to a multiplexer. The analog signal conditioning stage in the data acquisition equipment selected has a low input bias current characteristics and is able to integrate incoming signals over several milliseconds, features that aid in noise reduction and consistent measurement of small signals.

The data acquisition system (multiplexer, amplifier and data logger) is sensitive to temperature changes and to electrical interference. These effects are minimized by mounting the system in a grounded metal enclosure in a closet within the conditioned space, with no exterior walls or windows.

The signals are evaluated and recorded in the data acquisition system, with downloads by modem performed daily. The thermocouples are scanned every minute, with an average temperature recorded every hour. The wood moisture content is expected to have a time constant of much more than an hour (though surface readings may change somewhat more rapidly). To minimize any irreversible effects of the excitation voltage on the wood, readings are taken hourly.

Other Measurement Parameters

In addition to the moisture content and temperature measurements in walls, the following data is being collected:

- Room temperature and relative humidity in three rooms of test house (average of 60 readings per hour)
- Outdoor air temperature (average of 60 readings per hour)
- Outdoor relative humidity (average of 60 readings per hour)
- Rainfall (hourly total)
- Wind speed and direction (speed readings taken every 5 seconds, averaged within wind directional bins for each hour.
- Horizontal solar radiation data collected at an airport about 3 miles from the research site will be available to the project.

Moisture Content Data

The relationship between moisture content and electrical resistance varies with wood species, according to published data (James 1988). In developing a relationship for this project, data for several softwood species similar to those used in wood frame construction have been combined. Although there is considerable absolute variation in resistance across species, the logarithmic relationship between moisture content and resistance tends to reduce the effect of this variation on estimated moisture content. The relationship derived for use in this project is presented in Figure 1.

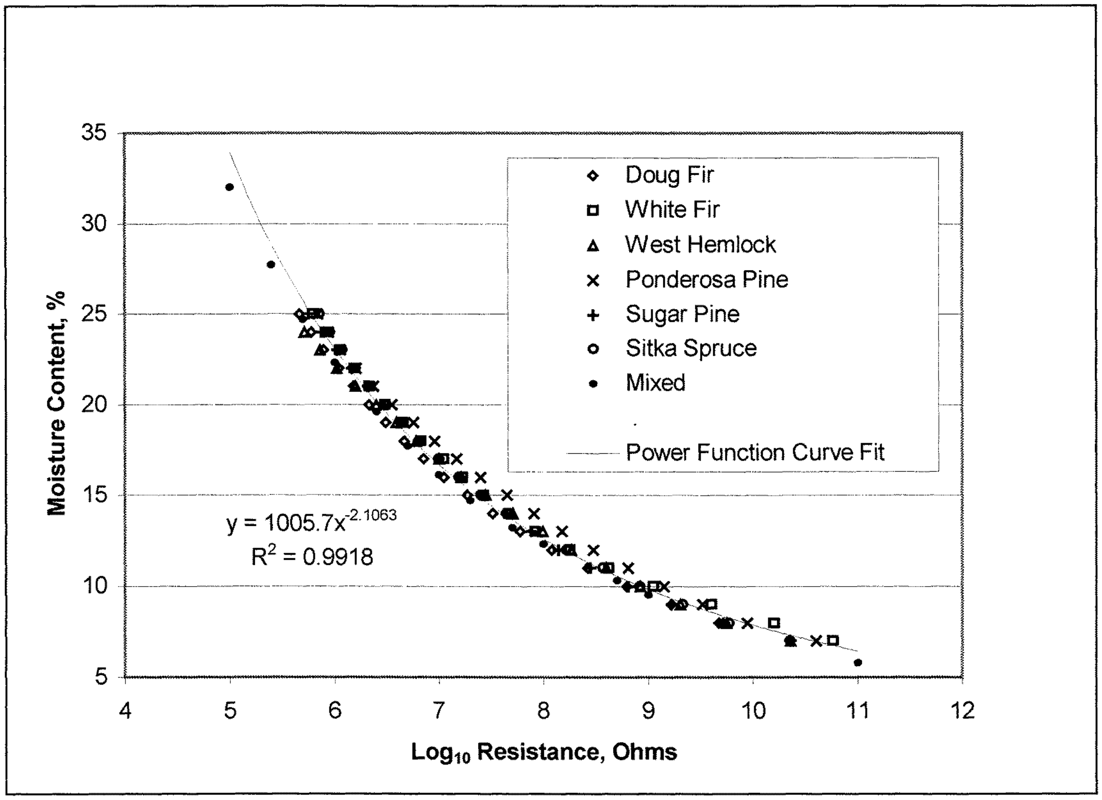

Figure 1. Moisture Content vs Log_{10} Resistance, Various Wood Species

Experimental Design

In order to meet the project objective of generating measurable moisture movement in the wall system, the indoor relative humidity is to be maintained at a high level most of the time. (Specific test conditions have not been determined.) Artificially high indoor RH also may contribute to condensation within the wall system in excess of that experienced in a normally occupied home. While this result may be inconsistent with expected wall system performance under typical occupied conditions, it will help in demonstrating the capability of the monitoring hardware and methods in identifying problematic moisture accumulation.

Conclusions

This project demonstrates a design and data collection methodology for gathering long-term moisture content and related data in a wood-frame home under field conditions. Data from the project will be the subject of future reports.

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